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(54) Abstract Title
Tyre condition monitoring system

(57) A tyre condition monitoring system has a wheel transmitter unit for each wheel of a vehicle. Signals from pressure and temperature sensors are compared with the output of a digital to analogue converter 7 to produce binary signals which control the outputs of a microprocessor 6. The wheel transmitter unit is operable in a normal operating mode in which data is transmitted by the transmitter and in a store mode in which pressure is sensed but no data is transmitted and in which the unit is responsive to a change in pressure to enter the normal mode. The wheel transmitter unit transmits from time to time data representing an identity code. The transmitter is arranged to respond to a change in one or more parameters by transmitting data more often, and the receiver unit is operable in a learning mode in which it responds to reception of data from a single transmitter unit more often by assigning to that transmitter unit a designated wheel position on a vehicle. The receiver unit is also operable in hand-held and in-vehicle modes.

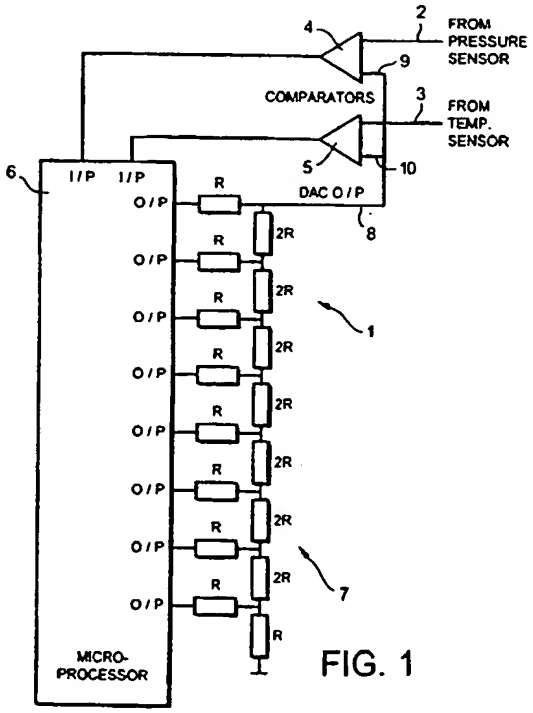

FIG. 1

GB 2 344 232 A

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

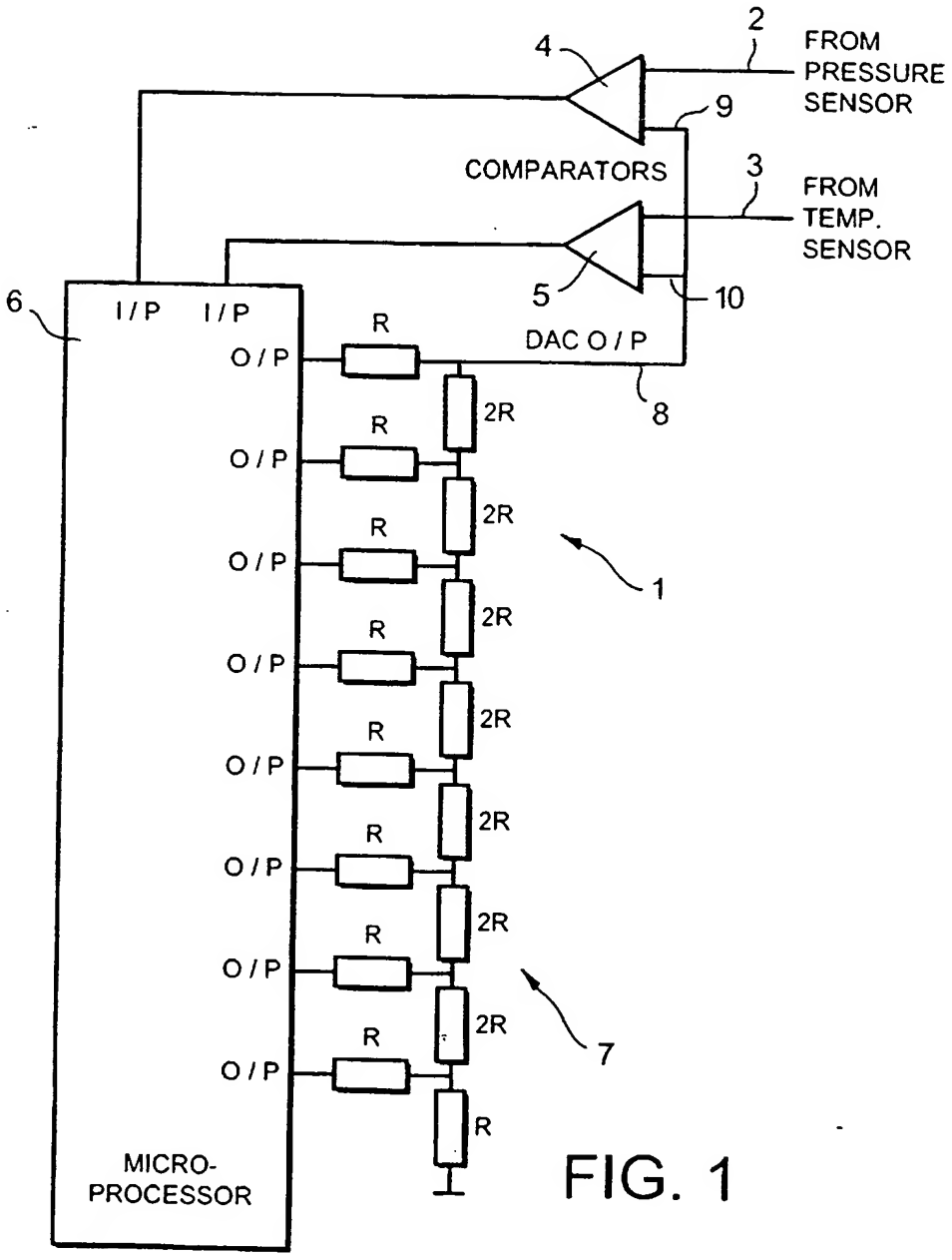
2
FROM
PRESSURE
SENSOR
4
9
COMPARATORS
3
FROM
TEMP.
SENSOR
5
10
6
I / P
I / P
DAC O / P
8
R
2R
O / P
1
7
MICRO-
PROCESSOR

FIG. 1

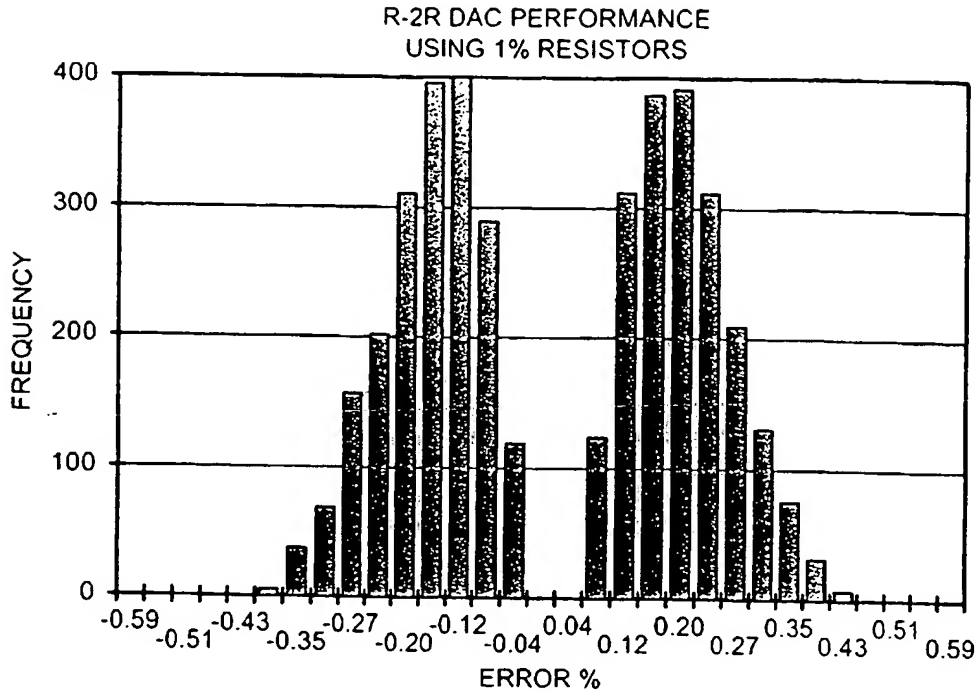

FIG. 2

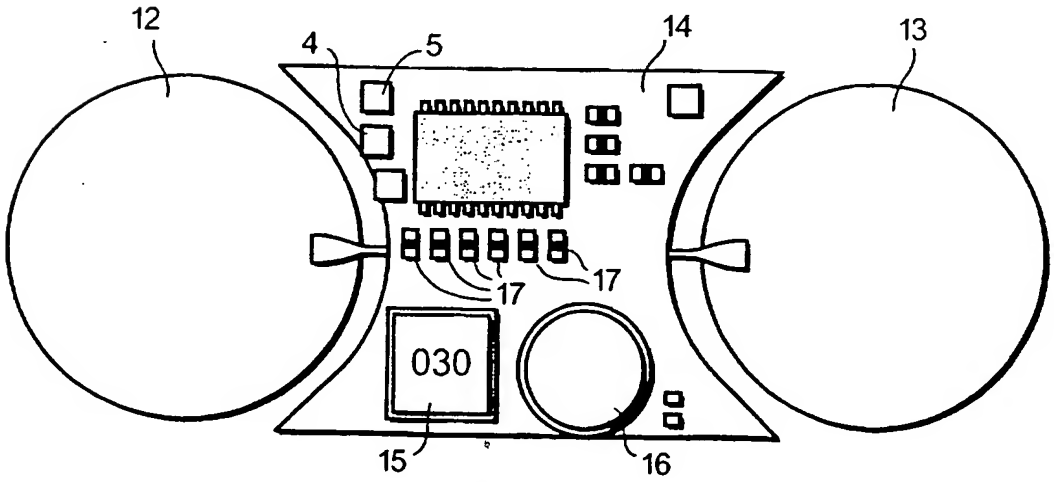

FIG. 3(a)

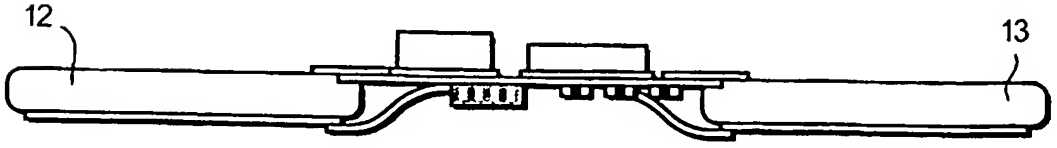

FIG. 3(b)

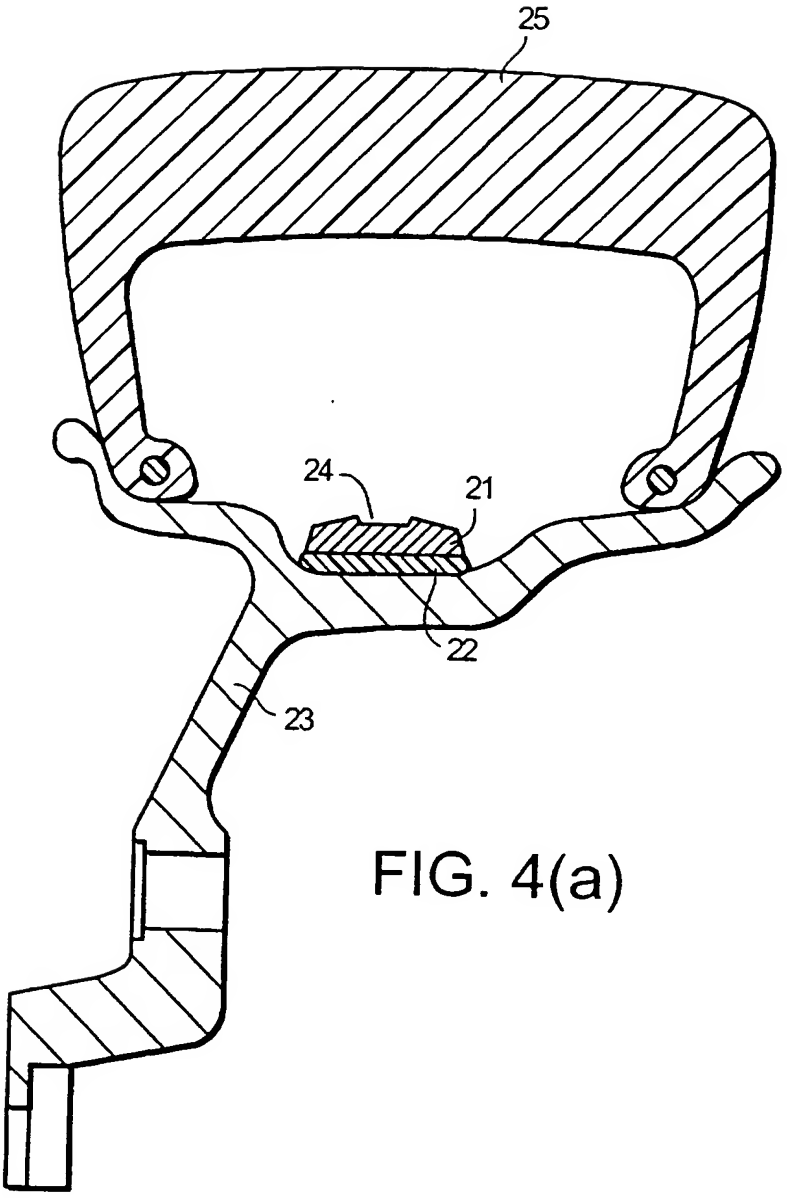

FIG. 4(a)

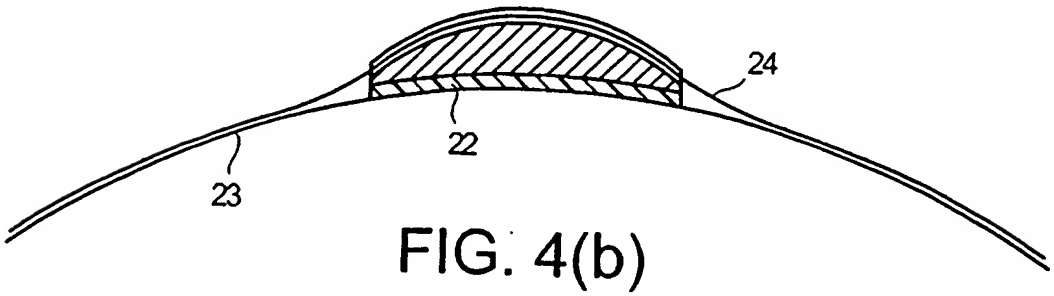

FIG. 4(b)

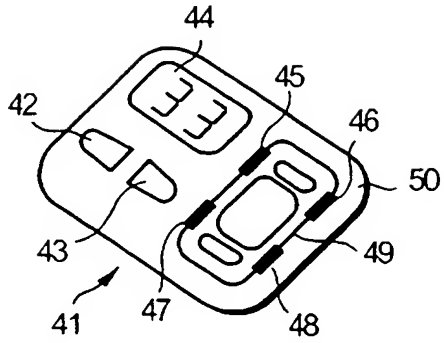
44
45
42
46
50
43
49
41
47
48

FIG. 6

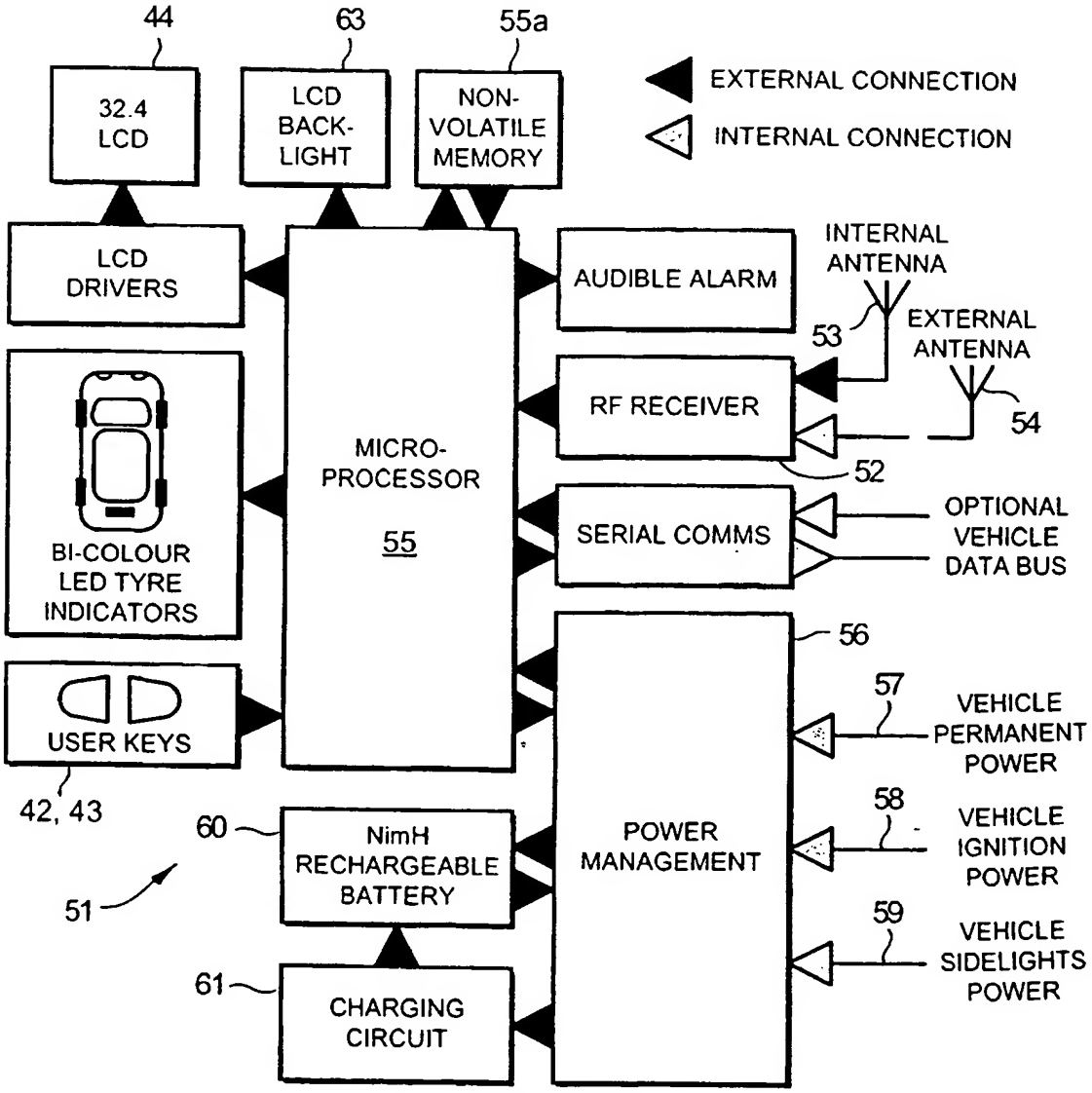
44
63
55a
32.4 LCD
LCD BACK-LIGHT
NON-VOLATILE MEMORY
EXTERNAL CONNECTION
INTERNAL CONNECTION
LCD DRIVERS
AUDIBLE ALARM
INTERNAL ANTENNA
EXTERNAL ANTENNA
53
RF RECEIVER
54
52
MICRO-PROCESSOR
55
SERIAL COMMS
OPTIONAL VEHICLE DATA BUS
BI-COLOUR LED TYRE INDICATORS
56
57
VEHICLE PERMANENT POWER
USER KEYS
42, 43
60
NimH RECHARGEABLE BATTERY
POWER MANAGEMENT
58
VEHICLE IGNITION POWER
51
59
VEHICLE SIDELIGHTS POWER
61
CHARGING CIRCUIT

FIG. 7

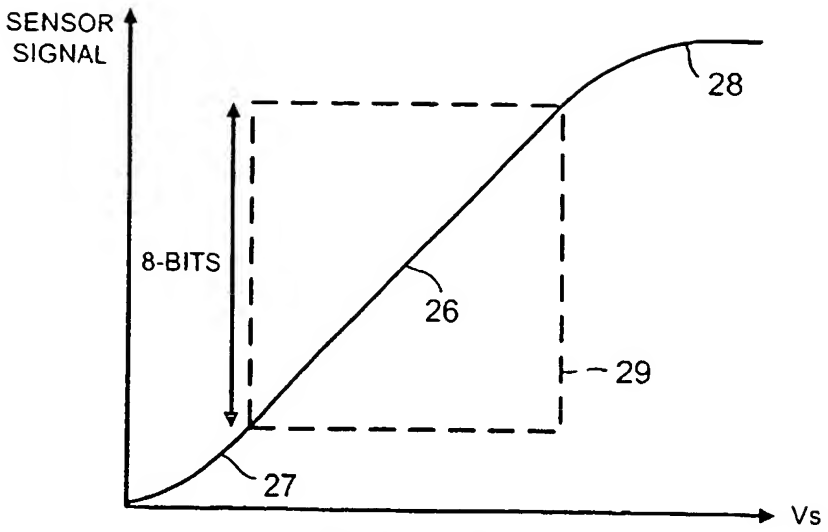

FIG. 5

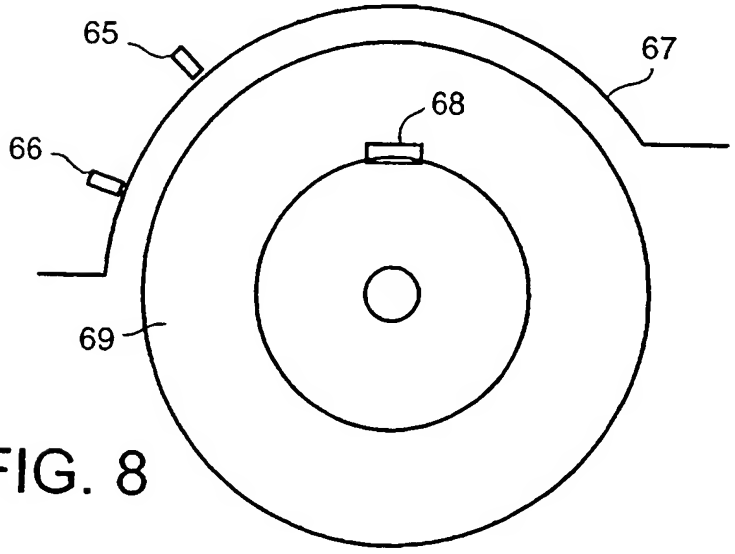

FIG. 8

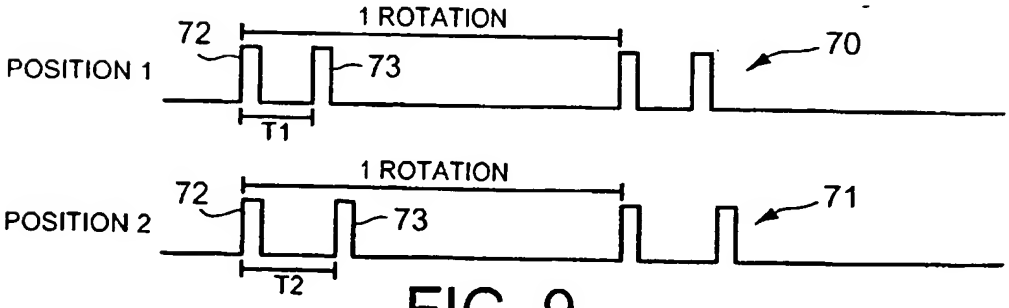

FIG. 9

A Tyre Condition Monitoring System

Field of the Invention

The invention relates to a digital circuit for processing an analogue signal, a tyre condition monitoring system, a wheel transmitter unit for a tyre condition monitoring system, and a receiver unit for a tyre condition monitoring system.

Background of the Invention

Tyre condition monitoring systems are used to monitor the condition of tyres on a vehicle in order to increase the safety and efficiency of the vehicle. There has been a great deal of interest in tyre monitoring in the past and some examples of recent proposals are disclosed in US-A-4,703,650, US-A-4,737,761, US-A-4,823,107, US-A-4,837,553, US-A-4,843,872, US-A-4,893,110, US-A-5,029,468 and US-A-5,054,315.

In our International Patent Application No. PCT/GB 93/02005 published as WO-A-94/06640, the teachings of which are incorporated herein by reference, we describe a tyre condition monitoring system comprising a unit mountable in a wheel of a vehicle. The unit comprises a sensor, a voltage controlled oscillator and a code generator arranged such that a coded signal is generated in a time period related to the value of the pressure or temperature sensed by the sensor. In order to conserve power the unit comprises a power supply which is activated by a timer from time to time causing the coded signal to be transmitted. Once the code has been transmitted the power supply is deactivated. The unit further comprises a monitor circuit which continuously monitors the sensor for an unacceptable pressure or temperature condition. An override circuit is responsive to the monitor circuit or to an external stimulus to activate the power supply.

In our International Patent Application No. PCT/GB 95/02060 published as WO-A-96/06747, the teachings of which are incorporated herein

by reference, we describe a tyre condition monitoring system comprising a wheel transmitter unit for each wheel of a vehicle. The transmitter unit is mountable in the wheel and has sensors for sensing pressure and temperature in and rotation of the wheel. Signals from the sensors are processed by a processor to produce data which is transmitted via a radio frequency transmitter. The data is transmitted with data representing a unit identity code. Transmitted data is received by a receiver unit where it is analysed to determine the condition of the tyre. The receiver unit includes a user operable input for setting threshold limits for the temperature and/or pressure such that if a threshold is passed an alarm is sounded. Each wheel transmitter unit includes a power supply and is arranged so that power is only applied during the sensing and transmission of data. Intervals between transmissions of data can be varied depending on whether rotation of the wheel has been sensed.

International Patent Application No. PCT/CA 92/00072 published as WO-A-92/14620 describes a tyre monitoring apparatus and method in which a code representing a measured physical quantity, property or condition of a tyre is transmitted. The circuit is operable in an active mode in which a measurement circuit measures an instantaneous value of temperature and pressure and a transmitter circuit transmits a signal representing the sensed instantaneous values of pressure and temperature. In the low power mode minimal power is consumed by the measurement and transmitter circuits.

Summary of the Invention

The present invention aims to provide among other things improvements in a digital circuit for processing an analogue signal, a tyre condition monitoring system, a wheel transmitter unit for a tyre condition monitoring system, and a receiver unit for a tyre condition monitoring system.

According to one aspect of the invention there is provided a digital circuit for processing an analogue signal, the circuit comprising: a comparator having a first input for receiving an analogue signal representing a value to be

processed, a second input for receiving an analogue signal, and an output for outputting a binary signal depending on signals applied to the first and second inputs; a processor having an input for receiving the binary signal, and a plurality of outputs for outputting a digital signal; and a resistor network connected to the plurality of outputs for converting the digital signal into a reference signal, and connected to the second input of the comparator to apply the reference signal thereto, and wherein the processor is arranged to vary the digital signal depending on changes in the binary signal, the digital signal thus representing a value proportional to the level of the analogue signal at the first input of the comparator.

According to another aspect of the invention there is provided a wheel transmitter unit for a tyre condition monitoring system, the wheel transmitter unit being mountable to a wheel and comprising: a sensor for sensing one or more parameters associated with said wheel and generating a signal representative thereof, a circuit as aforementioned for receiving the signal from the sensor, and a transmitter for transmitting data representing the sensed one or more parameters.

According to a further aspect of the invention there is provided a tyre condition monitoring system, comprising: a receiver unit for receiving data transmitted by at least one wheel transmitter unit mountable in the wheel of a vehicle and for monitoring the received data, the receiver unit being operable in hand-held and in-vehicle modes.

In another aspect the invention provides a tyre condition monitoring system, comprising: at least one wheel transmitter unit mountable in the wheel of a vehicle; and

a receiver unit for receiving the data transmitted by the at least one wheel transmitter unit and monitoring the received data, and wherein the wheel transmitter unit is operable to transmit from time to time data representing one or more parameters pertaining to the wheel and representing an identity code

pertaining to the transmitter unit, the transmitter unit being arranged to respond to a change in said one or more parameters by transmitting data more often, and the receiver unit is operable in a learning mode in which it responds to reception of data from a single transmitter unit more often by assigning to that transmitter unit a designated wheel position on a vehicle.

In a further aspect the invention provides a wheel transmitter unit for a tyre condition monitoring system, the wheel transmitter unit being mountable to a wheel and comprising: a sensor for sensing one or more parameters associated with said wheel and generating a signal representative thereof. a processing circuit for processing the signal from the sensor to produce parameter data representing the sensed one or more parameters, and a transmitter for transmitting the parameter data, and wherein the unit is operable in a normal operating mode in which data representing the one or more sensed parameters is transmitted by the transmitter, and is operable in a store mode in which the parameter is sensed but no data is transmitted and in which the unit is responsive to a change in a sensed parameter to enter the normal mode.

The above and further features of the invention are set forth with particularity in the appended claims and together with advantages thereof will become clearer from consideration of the following detailed description of an exemplary embodiments of the invention given with reference with the accompanying drawings.

Brief Description of the Drawings

In the drawings:

Figure 1 shows part of an electronic circuit for a wheel sensor module;

Figure 2 is a histogram of performance of the circuit of Figure 1;

Figure 3 shows (a) a plan view and (b) a side view of a sensor module;

Figure 4 shows (a) an end section view through a wheel including a sensor module and (b) a side section view through the wheel and sensor;

Figure 5 is a graph showing a transfer characteristic of the circuit of Figure 1;

Figure 6 is a schematic diagram of a removable unit embodying the invention;

Figure 7 shows circuitry associated with the removable unit;

Figure 8 is a schematic diagram of a sensor detecting arrangement; and

Figure 9 is a signal diagram showing a examples of signals received using the arrangements similar to that in Figure 8.

Detailed Description of an Embodiment of the Invention

In tyre condition sensing it is desirable to provide tyre sensor modules with a long working life. Sensor modules are mounted within the well of a wheel (as described in our aforementioned International patent applications for example) and are only accessible by removal of the tyre. Ideally, therefore, the working life of a sensor module should equal the typical life of a tyre. Tyres can last for several years. Such module life can be achieved by arranging the circuitry to switch off when the wheel is not in use.

Typically signals from pressure and temperature sensors within a tyre sensor are converted into digital form using a proprietary analogue to digital converter (ADC) for processing by a suitable processing circuit. Indeed ADCs and microprocessors are available as a single package. However, such devices are generally power hungry and will not operate accurately with a supply voltage of 3 volts or less.

Figure 1 of the accompanying drawings shows part of an electronic circuit 1 for a wheel sensor module embodying the invention. The circuit 1 is concerned with processing analogue signals from pressure and temperature sensors (not shown). It should be noted that the circuit 1 does not include an analogue to digital converter. Sensor signals are input via lines 2,3 to respective comparators 4,5. Signals from the comparators 4,5 are input to corresponding input lines of a processor 6. The processor is preferably a

PIC16LV58 or a similar low power device, capable of operating below 2 volts. The processor has eight output lines O/P to which an R-2R network 7 is connected as shown. The R-2R network serves to convert digital values from the output lines of the processor into a voltage which is output on an output line 8. In other words, the R-2R network is a digital to analogue converter. The output voltage on line 8 is applied to the other inputs 9,10 of the comparators 4,5. The comparators 4,5 thus convert the analogue signals from the sensors into an on/off digital signal, depending on whether the signal voltages are greater than or less than the voltage on the output line 8.

The circuit 1 enables the analogue signals from the sensors to be analyzed digitally. The signal output from the R-2R network is compared with the signals from the sensors. The processor adjusts the digital values output on the output lines O/P until the signal value output from the network crosses the value of the sensor signal. When the values cross the digital value at the output lines O/P is stored as the value of the sensor signal.

The process can be made very quick by arranging for the processor to start with a value that is the same as the value for the previous measurement. The processor then adjusts the value up and down until the comparators go through a transition. If the values of temperature and pressure have not changed significantly since the last measurement (which is most often the case) the time taken to determine the values of the signals is very quick, typically 10uS. Even if the values have changed significantly since the last measurement, then the conversion time will, typically, be less than 1mS.

The network may be fabricated using standard 1% tolerance surface mount resistors (for example of the 0603 type) which gives a very compact architecture similar in size to a standard 16 pin DIL surface mount chip. In tests the circuit 1 has been found to operate with a supply voltage of 1.8 volts, with a conversion dynamic range from decimal 4 to decimal 255, giving a resolution of less than 0.5%. Figure 2 of the accompanying drawings is a

histogram illustrating Monte-Carlo analysis of system performance in terms of tolerance spread in production of some 2000 test units. It should be noted that 0.4% error corresponds to an error of 1 LSB. Thus, readily available and cheap components can be used to achieve accurate performance down to less than 2 volts. A single lithium cell can provide a voltage between 2.4 and 3.4 volts in normal use and may have an end life voltage of 1.8 volts. The circuit 1 is therefore well suited to use where low power consumption is required.

Figure 3 of the accompanying drawings shows (a) a plan view and (b) a side view of a sensor module 11 comprising two lithium cells 12, 13 connected to supply power to circuitry on a board 14. The circuitry includes pressure and temperature sensors 15, 16, the processor 6, the comparators 4, 5, and resistors 17 which together form the R-2R network 7 illustrated in Figure 1. For the sake of clarity interconnecting tracks on the board are not shown.

Figure 4 of the accompanying drawings shows (a) an end view and (b) a side view of a sensor module 21 on a foam mount 22 secured to the rim 23 of a wheel by a retention strap 24. As can be seen in Figure 4 the sensor module 11 shown in Figure 3 is encased in a suitable material to protect the circuitry and the batteries and to provide support for the retention strap 24. The sensor module 21 is contained within the wheel by a tyre 25 and therefore is not readily accessible when in use.

The sensor module is active all the time, sampling sensor signals as described above, calculating parameters associated with the tyre pressure and transmitting data when necessary as described in our aforementioned International Patent Application No. PCT/GB 95/02060. Under normal conditions there will not be any significant and/or sudden changes in either the temperature or pressure of the tyre. The sensor module is therefore arranged under normal conditions to sample the signals from the sensors roughly every two seconds (or some other suitable interval). The processor is able to determine pressure to 8-bit accuracy using a variable dynamic range

window (described in detail herein below) which enables an accuracy of 0.1 psi to be obtained in the least significant bit, i.e. the least significant bit of the 8-bit number changing between 0 and 1 corresponds to a pressure change of 0.1 psi. A change of 1 bit between 0 and 1 is therefore ignored unless it is part of an ongoing sequence of changes in values. For the processor initially to react to a change between sensor values, the change must be significant (say 1 psi. or 1° C).

If the processor 6, on obtaining a sample of the sensor signals, determines that there has not been a significant change in either pressure or temperature since the last sensing, then the processor will then determine whether or not to transmit data. If less than, say, 20 minutes has passed (as determined by counting the number of 2 second sampling intervals since the last transmission) the processor causes the module to go into a sleep mode (as described in our earlier patent application) and no transmission occurs. If, however, there has been no transmission of data for 20 minutes, the processor causes the data to be transmitted (as described in our earlier patent application) before returning to the sleep mode.

The rate at which sensor signals are sensed and data is transmitted is increased greatly when a significant change in pressure or temperature occurs. For example when a tyre is deflated or inflated the pressure and temperature will change significantly in a short period of time. When the processor detects a significant change it increases the sampling rate to, say, every 0.5 seconds. The transmission rate is similarly increased. The sampling and transmission rates may be varied depending on the magnitude of the change, with the rates being increased less for a small change than for a larger change. After a predetermined period of time during which there is no further significant change (e.g. 16 seconds) the processor reverts to slower sampling and transmission rates to conserve power.

Once the circuit has been suitably encased, it is not possible to gain access to the circuitry therein. In normal use the sensor is arranged to monitor and transmit substantially continuously, albeit at a reduced rate during periods when there is no change in conditions. In order to conserve battery power and thus extend the shelf life of the sensor modules before they are fitted to vehicles, during the manufacturing process each sensor is placed in a "store" mode in which pressure and temperature is sensed but no data is transmitted. In the store mode the processor monitors for a significant change in pressure and to come out of the store mode into its normal operating mode when a change is detected. If the sensor is arranged to monitor for a significant increase in pressure then activation of the sensor in the normal mode will coincide with a tyre being inflated for the first time after a sensor has been fitted to a wheel. Once a sensor has come out of the store mode into its normal operating mode it will not return to the store mode but will continue to operate a s described herein for the rest of its working life. i.e. until the batteries are exhausted.

Figure 5 of the accompanying drawings represents the typical dynamic range of the sensor amplifiers associated with each sensor. The horizontal axis V_s represents the sensor voltage and the vertical axis. sensor signal. represents the amplified sensor signal to the comparators output on line 8. The transfer function is not linear because the amplifiers saturate and cannot output values close to the battery supply voltage. This is significant for low voltage analogue circuits (for example less than 3 volts). Instead the transfer function follows the form of a so-called "S-curve". As such the transfer function comprises a central linear portion 26 connecting two curved end portions 27, 28. In the end portions 27, 28 of the S-curve a large change in input will result in a relatively small change in output (as compared the same change in the linear portion 26). In a low power device, such as the circuit 1, it is useful to be able to optimise the range of values represented by the output signal.

Therefore, in order to optimise performance of the circuit 1, the values of components are selected to define a window 29 of operation in which a linear change of input will give a linear change in the 8-bit output of the ADC (line 8 in Figure 1). The window 29 is produced as a result of careful selection of component values.

Figure 5 represents the typical dynamic range of the sensor amplifiers associated with each sensor. The transfer function is not linear because the amplifiers saturate and cannot output values close to the battery supply voltage. This is particularly significant for low voltage analogue circuits (e.g. less than 3 volts). Instead the curve follows the so-called "S-Curve". As such the transfer characteristic comprises a central linear portion.

Ideally one should aim to gain the maximum accuracy and resolution of the measurement circuits, so as to utilise the central linear portion of the curve for the entire dynamic range of the digital-to-analogue converter. Thus it is possible, using resistors in both the sensor amplifier circuits and the R-2R network (not shown), to ensure that the desired dynamic range of the sensors and the full dynamic range of the R-2R network output lies within the linear part of the amplifier S-Curve.

The linearity and resolution can be improved by ensuring that the output of the sensor amplifiers and the R-2R network lie within the same linear region of the transfer function, identified as a window 29 in Figure 5.

This ability to define the dynamic range of measurement also allows for adjustment of sensitivity and range for both pressure and temperature. For example, for motor sport applications it is beneficial to use the full 8 bits (256 level) dynamic range of the analogue to digital conversion for a pressure range of 10 psi to 35 psi, thus giving a 0.1 psi resolution. A value from the analogue to digital conversion of zero would therefore represent 10 psi and 255 would represent 35 psi, thus maximising conversion dynamic range. For HGV applications it may be required to have a pressure range of 0 to 100 psi.

In some applications it is preferable to select a particular sensitivity pressure sensor in addition to optimising the active "Window" of analogue signal measurement.

The remainder of the circuitry comprising the wheel sensor module is not shown and will not be described herein because it is substantially the same as that described in our aforementioned International Patent Application No. PCT/GB 95/02060.

Figure 6 of the accompanying drawings shows a removable unit 41 which may be hand-held or mounted at a station (not shown) at a convenient location within a vehicle. The removable unit 41 comprises control buttons 42,43, a display 44, and LEDs 45 to 48. A schematic representation 49 of a car is printed or otherwise applied to the upper surface 50 of the removable unit 41. The representation enables the LEDs to be seen in the context of the wheels of the vehicle to which they pertain. The control buttons are connected to switches (not shown) which enable the removable unit to be controlled. In response to manipulation of the control buttons 42,43 the display is caused to display pressure, temperature and/or other data relating to the wheel whose LED 45 to 48 is illuminated. The LEDs may be dual colour devices with one colour, e.g. red, representing a hazard (low pressure, high temperature, etc.) and another colour, e.g. green, representing a normal or safe condition.

The removable unit 41 contains electronic circuitry (shown in Figure 7) which receives signals transmitted from sensor modules mounted in each wheel of a vehicle. Turning now to Figure 7, there is shown an electronic circuit 51 comprising a radio frequency (RF) receiver 52 connected to receive signals from an internal antenna 53 and connectable to receive signals from an external antenna 54. The internal antenna is used when the removable unit 41 is being used in a hand-held mode and the removable unit is connected to the external antenna when the removable unit is being used in in-vehicle modes. The external antenna 54 is provided to improve the sensitivity of the

removable unit to signals transmitted from the sensor module in each wheel. Signals from the sensor modules are very low power, both to conserve energy and to comply with international radio transmission regulations. The received signal level within the vehicle cabin is therefore extremely low power and in some circumstances it is necessary to utilise the external antenna for reliable reception. When the receiver/display unit is used externally to the vehicle, the unit's internal antenna is sufficient for picking up the signals because of the reduced attenuation caused by the vehicle body. The various modes of operation will be described in detail hereinafter. Signals received by the RF receiver 52 are converted into digital form by way of suitable demodulators and decoders (not shown) for input as digital data to a processor 55.

The processor 55 has associated with it a non-volatile memory 55a containing a suitable program to enable the processor to process the digital data input thereto. The processor 55 processes the data to determine therefrom the sensor module from which the data has been received and the pressure and temperature sensed by that sensor. The processing of the digital data is substantially the same as described in our aforementioned International Patent Application No. PCT/GB 95/02060 and therefore will not be described any further herein.

The processor 55 also controls operation of the removable unit in response to manipulation of the buttons ("user keys") 42,43 and signals from a power management circuit 56. The removable unit 41 is arranged to be mounted in a vehicle at any suitable location (e.g. the dashboard) where it is connected by suitable connectors (not shown) to three power lines 57 to 59 from the vehicle. One of the power lines 57 is the vehicle's permanent power, i.e. the battery. When the removable unit is installed in a vehicle the power management circuit 56 uses the vehicle power to power the circuit 51 and charge a rechargeable battery 60 via a charging circuit 61. Another of the power lines 58 is power from the ignition of the vehicle. This power line 58 is

only on when the vehicle itself is switched on. The other power line 59 is power from the vehicle's sidelights. In this embodiment the display 44 is a liquid crystal device (LCD) and when the sidelights line 59 is live the power management circuit 56 sends a signal to the processor 55 causing the processor to activate a backlight 63 for the display 44.

The circuit 51 has several different modes of operation. The following modes will now be described, namely: in-vehicle standby: in-vehicle active; and hand-held. If the removable unit 41 is installed in the vehicle when the vehicle is not being used, power is detected by the power management circuit 56 on the permanent power line 57, but not on the ignition power line 58. This causes the removable unit to enter the in-vehicle standby mode. In this mode the power management circuit 56 supplies power from the line 57 to the circuit 51 and enables the charging circuit 61 to trickle-charge the battery 60. Since the removable unit is installed in the vehicle the RF receiver 52 is connected to the external antenna and receives signals therefrom. Monitoring of the signals is continuous, but it is assumed that there will be no one to react to the (unlikely) detection of adverse tyre conditions. The display 44 is therefore arranged to indicate a standby mode and the backlight 63 is switched off. Likewise the LEDs 45 to 48 are extinguished.

If the unit 41 is installed in the vehicle when the vehicle is being used, power is detected by the power management circuit 56 both on the permanent power line 57 and the ignition power line 58. This causes the unit to enter the in-vehicle active mode. In this mode the power management circuit 56 again supplies power from the line 57 to the circuit 51 and enables the charging circuit 61 to trickle-charge the battery 60. Signals are received by the RF receiver 52 via the external antenna 53. The processor 55 processes the data in the received signals and outputs for display pressure or temperature values depending on the last manipulation of the user keys 42,43. The processor also drives the LEDs 45 to 48 to indicate either a "good" condition (green) or a

"not good" condition (red) as appropriate. The circuit 51 also includes an audible alarm 65 which may be activated by the processor 55 in the event of a "not good" condition being detected in on or more of the tyres. The processor 55 responds to manipulation of the user keys 42,43 by cycling through the wheels of the vehicle and displaying pressure or temperature values (also selected by manipulation of the keys) for each wheel in turn on the display 44. An appropriate one of the LEDs 45 to 48 is illuminated to indicate to which of the wheels the data currently being displayed relates. If the vehicle sidelights power is detected, the microprocessor will automatically (if desired by the user) reduce the brightness of the backlight, thus preventing unnecessary glare in low light conditions when sidelights are likely to be used.

If the removable unit 41 is removed from the vehicle, power is not detected by the power management circuit 56 on the permanent power line 57 or on the ignition power line 58. This causes the unit to enter the hand-held mode. In this mode the power management circuit 56 does not supply any power until one of the buttons 42,43 is pressed. When a button is pressed the power management circuit 56 supplies power from the battery 60 for a predetermined period of time, e.g. 2 minutes. Since the unit is not installed in the vehicle the RF receiver 52 is connected only to the internal antenna 53 and receives signals therefrom. Monitoring of the signals occurs only while the unit is powered by the battery 60, when the power management circuit 56 removes the power monitoring is suspended. When power is supplied from the battery, the display 44 displays pressure and temperature data and the LEDs 45 to 48 are illuminated for the selected wheel, either green or red to indicate a "good" or "not good" condition. The audible alarm will also be activated by the processor in the event of a "not good" condition being detected. The backlight 63 is switched off.

When a set of sensors is fitted to the wheels of a vehicle it is, of course, necessary for the removable unit 41 to be able to determine which

signal is being received from which sensor. As is described in our aforementioned International patent application, every sensor has a unique identification code associated with it. Therefore, with a suitable input of information the unit 41 can be programmed to attribute the received signals with a given sensor in a given wheel. Whilst this approach is satisfactory, it does nevertheless require a level of expertise on the part of the installer. This requirement means that it is not a simple matter to change the position of the wheels on the car; such as change requires reprogramming of the removable unit and is therefore dependent on the person changing the wheels to have the necessary skills to do that.

One arrangement which simplifies the identification of sensor locations is illustrated in Figure 8 of the accompanying drawings. As shown therein, two magnets 65. 66 are fitted to the body 66 of a vehicle at convenient spaced apart locations. The magnets create magnetic fields in the vicinity of a sensor 68 mounted in a wheel 69 of the vehicle. A hall effect device (not shown) in the sensor 68 detects movement of the sensor 68 through the magnetic fields and produces a signal similar in form to that of the signals 70, 71 shown in Figure 9 of the accompanying drawings. Referring to the signal 70, for each rotation of the wheel the hall effect device will produce two pulses 72. 73 spaced apart in time by a period T_1. If pairs of magnets are mounted on the body of the vehicle such that for each sensor the distance between the magnets is different, then the resulting signals 70. 71 in each sensor will have pulses 72. 73 spaced apart by a different time period T_1, T_2. Since the time period T_1. T_2 will be different for each wheel it is possible to distinguish the sensor signals from one another.

An alternative approach takes advantage of the feature of the sensors being arranged to increase greatly the rate at which sensor signals are sensed and data is transmitted when a significant change in pressure or temperature occurs. In addition to the above described in-vehicle standby, in-vehicle

active, and hand-held modes, the circuit 51 in the removable unit 41 (see Figure 7) is operable in a learning mode. The microprocessor 55 is arranged to respond to predetermined manipulation of the user keys 42, 43 by entering the learning mode. For example, the processor 55 may be arranged to respond to the keys 42, 43 both being depressed for, say, 5 seconds. Once the learning mode has been entered the user is prompted via the display 44 and the LEDs 45 to 48 to change the pressure in a tyre, for example by releasing pressure in the tyre so as to deflate it. This sudden change in pressure causes the sensor therein to transmit data. The transmitted data includes an identity code (as described in our aforementioned International application no. PCT/GB 95/02060) which enables the identity of the sensor at the prompted location to be identified. In order to increase the certainty of the identification process, the circuit 51 may be arranged to wait for, say, three transmissions with identical codes before confirming the position of the sensor on the vehicle.

It will be appreciated that it is not necessary to perform the above described learning operation at a vehicle. It is possible to carry out the operation at any convenient location. Also, the simple nature of the learning process means that preprogramming of the sensors or the removable unit 41 is unnecessary. Therefore, it is possible to supply sensors separately, rather than as part of a set included with the removable unit 41.

Having thus described the invention by reference to a preferred embodiment it is to be well understood that the embodiment in question is exemplary only and that modifications and variations such as will occur to those possessed of appropriate knowledge and skills may be made without departure from the spirit and scope of the invention as set forth in the appended claims and equivalents thereof.

CLAIMS:

1. A digital circuit for processing an analogue signal, the circuit comprising:

a comparator having a first input for receiving an analogue signal representing a value to be processed, a second input for receiving an analogue signal, and an output for outputting a binary signal depending on signals applied to the first and second inputs:

a processor having an input for receiving the binary signal, and a plurality of outputs for outputting a digital signal: and

a resistor network connected to the plurality of outputs for converting the digital signal into a reference signal, and connected to the second input of the comparator to apply the reference signal thereto,

and wherein the processor is arranged to vary the digital signal depending on changes in the binary signal, the digital signal thus representing a value proportional to the level of the analogue signal at the first input of the comparator.

2. A circuit as claimed in claim 1, wherein the comparator is arranged to compare the level of the analogue signal at the first input and the level of the analogue signal at the second input and to output a binary signal of one value if the level of the analogue signal at the first input is greater than that at the second input and to output a binary signal of another value if the level of the analogue signal at the first input is less than that at the second input.

3. A circuit as claimed in claim 1 or 2, further comprising a second comparator having a first input for receiving an analogue signal representing a value to be processed, a second input connected to receive the reference signal, and an output for outputting a binary signal depending on the signals applied to the first and second inputs,

and wherein the processor comprises a second input connected to receive the binary signal output from the second comparator and is arranged

to vary the digital signal depending on changes in the binary signal from the second comparator, the digital signal thus representing a value proportional to the level of the analogue signal at the first input of the second comparator.

4. A circuit as claimed in any preceding claim, wherein the analogue signal is proportional to sensed pressure and the digital signal represents a pressure value.

5. A circuit as claimed in any preceding claim, wherein the analogue signal is proportional to sensed temperature and the digital signal represents a temperature value.

6. A wheel transmitter unit for a tyre condition monitoring system, the wheel transmitter unit being mountable to a wheel and comprising:

a sensor for sensing one or more parameters associated with said wheel and generating a signal representative thereof.

a circuit as claimed in any preceding claim for receiving the signal from the sensor, and

a transmitter for transmitting data representing the sensed one or more parameters.

7. A wheel transmitter unit as claimed in claim 6, wherein the processor is arranged to process the digital signal representing the sensed one or more parameters to produce parameter data, the processor being operable in a normal operating mode in which data representing the one or more sensed parameters is transmitted by the transmitter.

8. A wheel transmitter unit as claimed in claim 7, wherein, in the normal operating mode, data representing the temperature of and pressure in the wheel is transmitted together with data identifying the wheel.

9. A wheel transmitter unit as claimed in claim 7 or 8, wherein the processor is operable in a store mode in which the parameter is sensed but no data is transmitted and in which the processor is responsive to a change in a sensed parameter to enter the normal mode.

10. A wheel transmitter unit as claimed in any of claims 6 to 9, wherein the data produced for transmission is in digital form.

11. A wheel transmitter unit as claimed in any of claims 6 to 10, wherein the processor is arranged to produce data identifying the wheel transmitter unit for transmission with the sensed parameter data.

12. A tyre condition monitoring system, comprising: a receiver unit for receiving data transmitted by at least one wheel transmitter unit mountable in the wheel of a vehicle and for monitoring the received data, the receiver unit being operable in hand-held and in-vehicle modes.

13. A tyre condition monitoring system as claimed in claim 12, wherein the receiver unit comprises an internal power supply; a power management circuit; and means for connecting the unit to power lines in a vehicle, and wherein the power management circuit is operable in the in-vehicle mode to detect connection to the power lines of a vehicle and to control supply of power from the power lines when connection is detected and in the hand-held mode to control supply of power from the internal power supply when no connection is detected.

14. A tyre condition monitoring system as claimed in claim 13, wherein the receiver unit comprises a radio frequency receiver connected to an internal antenna and means for connecting the receiver to an external antenna, the receiver being arranged to receive signals from the at least one wheel transmitter unit via the external antenna when connected thereto in the in-vehicle mode and to receive signals from the at least one wheel transmitter unit via the internal antenna when not connected to the external antenna in the hand-held mode.

15. A tyre condition monitoring system as claimed in claim 12 or 13, wherein the receiver unit comprises a processor for processing signals received by the receiver and outputting data for display of information representing sensed parameters, the unit being operable in an in-vehicle standby mode in

which no information is displayed and an in-vehicle active mode in which information is displayed.

16. A tyre condition monitoring system as claimed in claim 15, wherein the receiver unit is arranged to enter a standby mode from the hand-held mode a predetermined period of time after the hand-held mode has been entered.

17. A tyre condition monitoring system as claimed in claim 15 or 16, wherein the receiver unit further comprises user operable means operable to select for display information representing one of the one or more sensed parameters for one of the at least one wheel transmitter unit.

18. A tyre condition monitoring system as claimed in claim 17, wherein the user operable input means comprises plural switches.

19. A tyre condition monitoring system as claimed in claim 17 or 18, wherein the receiver unit further comprises a display for displaying values of the one or more parameters sensed by the at least one wheel transmitter unit.

20. A tyre condition monitoring system as claimed in claim 19, wherein the display comprises a digital display for displaying values of the one or more sensed parameters and a graphical display for indicating the nature of the displayed value and the wheel unit to which the displayed value relates.

21. A tyre condition monitoring system as claimed in claim 20, wherein the graphical display comprises plural dual-colour light emitting diodes each pertaining to a respective wheel of a vehicle.

22. A tyre condition monitoring system as claimed in any of claims 12 to 21 in combination with a wheel transmitter unit as claimed in any of claims 6 to 11 serving as said at least one wheel transmitter unit.

23. A tyre condition monitoring system, comprising:

at least one wheel transmitter unit mountable in the wheel of a vehicle; and

a receiver unit for receiving the data transmitted by the at least one wheel transmitter unit and monitoring the received data, and

wherein the wheel transmitter unit is operable to transmit from time to time data representing one or more parameters pertaining to the wheel and representing an identity code pertaining to the transmitter unit, the transmitter unit being arranged to respond to a change in said one or more parameters by transmitting data more often. and the receiver unit is operable in a learning mode in which it responds to reception of data from a single transmitter unit more often by assigning to that transmitter unit a designated wheel position on a vehicle.

24. A tyre condition monitoring system as claimed in claim 23. wherein the receiver is operable in the learning mode to respond to a plurality of receptions of the same code by assigning the designated wheel position.

25. A tyre condition monitoring system as claimed in claim 23 or 24, wherein the receiver unit further comprises user operable means operable to designate a wheel position in the learning mode.

26. A tyre condition monitoring system as claimed in claim 25. wherein the user operable input means comprises plural switches.

27. A tyre condition monitoring system as claimed in any of claims 23 to 26. wherein the receiver unit further comprises a display for displaying a representation of a designated wheel position.

28. A tyre condition monitoring system as claimed in claim 27, wherein the display comprises a graphical display for indicating a designated wheel.

29. A tyre condition monitoring system as claimed in claim 28, wherein the graphical display comprises plural dual-colour light emitting diodes each pertaining to a respective wheel of a vehicle.

30. A wheel transmitter unit for a tyre condition monitoring system, the wheel transmitter unit being mountable to a wheel and comprising:

a sensor for sensing one or more parameters associated with said wheel and generating a signal representative thereof,

a processing circuit for processing the signal from the sensor to produce parameter data representing the sensed one or more parameters, and

a transmitter for transmitting the parameter data, and

wherein the unit is operable in a normal operating mode in which data representing the one or more sensed parameters is transmitted by the transmitter, and is operable in a store mode in which the parameter is sensed but no data is transmitted and in which the unit is responsive to a change in a sensed parameter to enter the normal mode.

31. A wheel transmitter unit as claimed in claim 30, wherein, in the normal operating mode, data representing the temperature of and pressure in the wheel is transmitted together with data identifying the wheel.

32. A circuit, a wheel transmitter unit or a monitoring system substantially as described herein.

The Patent Office

Application No:	GB 9822671.5	**Examiner:**	John Donaldson
Claims searched:	1 to 11, 22	**Date of search:**	5 November 1998

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.P): H3H(HAV)

Int Cl (Ed.6): H03M 1/00, 1/12, 1/34, 1/38, 1/40, 1/46

Other: Online:WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	GB 2048000 A	(GRASS VALLEY), see page 3, lines 66 to 122	1 to 3
X	GB 1580441	(AEI), see page 2, line 104 to page 3, line 15	1, 2
X	GB 1425218	(WESTERN ELECTRIC), see page 2, line 122 to page 4, line 11	1, 2

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

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The Patent Office

Application No:	GB 9822671.5	**Examiner:**	John Donaldson
Claims searched:	12 to 21	**Date of search:**	3 February 1999

Patents Act 1977
Further Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.Q): G1N(NAHJA, NAHJC, NAHJD); G4N(NCPT)

Int Cl (Ed.6): B60C 23/00, 23/02, 23/04, 23/06, 23/20; G08C 17/00, 17/02

Other: Online:WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
A	US 4308520 (DARLINGTON), see abstract	-

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
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The Patent Office

Application No:	GB 9822671.5	**Examiner:**	John Donaldson
Claims searched:	23 to 29	**Date of search:**	3 February 1999

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Further Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.Q): G1N(NAHHA, NAHJA, NAHJD)

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Other: Online:WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
A	EP 0806306 A2 (CONTINENTAL), see abstract	-

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

The Patent Office

Application No:	GB 9822671.5	**Examiner:**	John Donaldson
Claims searched:	30, 31	**Date of search:**	3 February 1999

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Further Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.Q): G1N(NAHHA, NAHJA, NAHJC, NAHJD); G4H(HNHE); G4N(NCPT)

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Other: Online:WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	GB 2047932 A	(GOULD), see abstract	30
X	GB 1489195	(BRIDGESTONE TIRE), see page 2, line 127 to page 3, line 25	30
X	EP 0806306 A2	(CONTINENTAL), see abstract	30
X	EP 0178613 A2	(NIETO LUEIMO), see column 1, lines 12 to 17	30
X	US 5289160	(FIORLETTA), see abstract	30

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.